52321-012

HEAT TEMPERATURE RAISING SYSTEM

Technical Field

This invention relates to a process and apparatus for raising heat temperature, i.e., transferring heat from a low temperature heat source to a higher temperature heat sink. More specifically, in one embodiment, the invention relates to a process and apparatus for transforming a heat carrying substance under a first pressure P_1 and producing a vapor of a second heat carrying substance at a second pressure P_2.

Background of the Invention

The process of the invention is based on the principle that the melting point of a substance changes as the applied pressure changes. A set of multiple heat conductive and pressure rated (i.e. pressurizable) conduits is connected with pressurizing equipment. Inside these conduits is a mass of Heat Temperature Raising Medium (HTR medium) which is capable of undergoing a phase change upon the application of pressure. When the HTR medium is subjected to a pressure variation, it allows the said medium to absorb and store heat at low temperature. After the HTR medium has absorbed and stored the heat at low temperature, a high pressure is applied to the HTR medium. This increase in pressure on the HTR medium causes the melting point of the medium to increase and allows the medium to release the heat it has stored to the higher surrounding temperature. Thus, the HTR medium can successfully elevate the temperature from a low temperature to a higher temperature. Another medium, Heat Carrying Medium (HCM medium), is used in the present invention to assist and complete the cycle of raising heat temperature from low temperature heat source to a higher temperature heat sink.

The use of a melting point inversion for water purification of saline water is disclosed in U.S. Patent number 3,354,083. This process requires a large sum of saline water and mediums to be exposed to high pressure and low pressure. Due to the difficulty of such operation, this process was unsuccessful. Hence there remains a need in the art for a process and apparatus which can make use of the latent heat of fusion and/or latent heat of evaporation of heat transfer materials to transfer heat without subjecting large quantities of process fluids to high pressure.

Disclosure of the Invention

It is accordingly an aspect of the invention to provide a process and apparatus for transferring heat from a heat source at one temperature to a heat sink at a higher temperature.

It is another aspect of the invention to provide a process and apparatus, as above, which accomplishes the heat transfer by effecting a phase change of a heat transfer medium using variable pressure to alter the temperature at which the phase change occurs.

It is another aspect of the invention to provide a process and apparatus, as above, which minimizes the amount of fluid subjected to the variable pressure.

Unlike the above prior process, the present invention maintains the Heat Temperature Raising Medium (HTR medium) inside conduits. By subjecting the HTR medium to a pressure fluctuation between low pressure and high pressure, the invention allows the HTR medium to absorb heat at low temperature and release heat at a higher temperature. Thus, the HTR medium can successfully elevate the heat temperature, i.e., transfer heat from a first temperature to a second, higher temperature without the need of exposing large quantities of materials to low pressure and high-pressure operation.

In the present invention, the high-pressure zone is preferably stationary and is secured inside a Heat Temperature Raiser (HTR unit), while the transportation of the heat between the low temperature source and high temperature sink is accomplished by the Heat Carrying Medium (HCM medium) operating at low pressure. Therefore, large quantities of material moving between low pressure and high-pressure operation are not required.

The present invention provides for a Heat Temperature Raising System, referred to as a HTR system, for taking in heat from a low temperature (T_L) heat source and supplying heat to a high temperature (T_H) heat sink. A HTR system comprises a heat temperature raising unit, referred as a HTR unit, a mass of heat temperature raising medium, referred to as HTR medium, and a mass of a first heat carrying medium, referred to as HCM-1 medium, and a mass of second heat carrying medium, referred to as HCM-2 medium. The system is divided into three compartments: a central compartment referred to as a HTR compartment, containing the HTR units, a heat source compartment and a heat sink compartment. There is a first valving means separating the heat source compartment and the HTR compartment and a second valving means separating the heat sink compartment and the HTR compartment.

The HTR unit is preferably a stationary unit, i.e., the HTR medium is not itself conveyed between the heat source and the heat sink. The HTR unit comprises a set of heat conductive and pressure sustaining conduits, a mass of HTR medium contained in the HTR unit and a pressurizer for pressurizing and depressurizing the HTR medium contained in the HTR unit.

The pressurizer can be, for example, a mechanical compressor such as a plunger mechanism, a steam source, or other compressive fluid source, or any other device which can apply substantially hydrostatic pressure to the HTR medium. The HTR medium is subjected to a series of cyclic operations that comprise melting under a first pressure and a first temperature, respectively referred to as a first HTR pressure and a first HTR temperature and solidifying under a second pressure and a second temperature, respectively referred to as a second HTR pressure and a second HTR temperature. A mass of first heat carrying medium HCM-1 is vaporized by receiving heat from the heat source to form a HCM-1 vapor and the vapor passes through the first valving means to come in contact with the HTR unit and melt the HTR medium. The HCM-1 vapor is thereby condensed to form a mass of HCM-1 condensate. Then, a mass of the second heat carrying medium HCM-2 is brought in contact with the HTR medium to thereby solidify the HTR medium under the second HTR pressure and temperature and thereby form a vapor stream of the second heat carrying medium, referred to as HCM-2 vapor. The HCM-2 vapor passes through the second valving means and releases heat to the heat sink and thereby condenses to form a condensate of HCM-2 medium. The condensate is recycled to the vaporization operation described. It is noted that since the HTR medium is preferably contained within a stationary HTR unit, it takes the first and second HCM medium to exchange heat with the heat source and the heat sink.

It is also within the scope of the invention to use the same medium for both HCM-1 and HCM-2. In this alternative, the HCM-1 condensate formed in the low temperature condensation operation may be used in the high temperature evaporation operation, and the HCM-2 condensate formed in the high temperature condensation operation may be used in the low temperature vaporization operation.

A HTR system can be used in providing chill water and air conditioning and used in vacuum freezing processes, in ice production processes, ice storage processes, distillative freezing processes and multi-effect evaporation processes.

Brief Description of the Drawings

For a full understanding of the invention, the following detailed description should be read in conjunction with the drawings, wherein:

Fig. 1 is a schematic illustration of one embodiment of an HTR system of the invention;

Fig. 2 illustrates one embodiment of an HTR unit of the invention;

Fig. 2A illustrates another embodiment of an HTR unit of the invention;

Fig 2B illustrates the structure of one embodiment of a longitudinal fin unit of the invention;

Fig. 2C is a partial cutaway view of an HTR unit containing the fin unit of Fig. 2B;

Fig. 3A is a cross-sectional view of one embodiment of a multiple connected conduit unit of the invention;

Fig. 3B is a cross-sectional view of the multiple conduit unit of Fig. 3A with longitudinal fin units installed;

Fig. 4A is a cross-sectional view of another embodiment of a multiple conduit unit of the invention;

Fig. 4B is a cross-sectional view of the conduit unit of Fig. 4A with longitudinal fin units installed;

Fig. 5A is a cross-sectional view of one embodiment of multi-void metal block unit of the invention;

Fig. 5B is a cross-sectional view of the multi-void metal block unit of Fig. 5A with longitudinal fin units installed;

Fig. 6A illustrates one embodiment of an HTR system of the invention with heat transfer from a first Heat Carrying Medium;

Fig. 6B illustrates the HTR system of Fig. 6A with heat transfer to a second Heat Carrying Medium;

Fig. 7A illustrates another embodiment of an HTR system of the invention with heat transfer from a first Heat Carrying Medium;

Fig. 7B illustrates the HTR system of Fig. 7A with heat transfer to a second Heat Carrying Medium;

Fig. 8A illustrates an embodiment of an HTR system of the invention which is useful in vacuum freezing with heat transfer from a first Heat Carrying Medium;

Fig. 8B illustrates the HTR system of Fig. 8A with heat transfer to a second Heat Carrying Medium;

Fig. 9A illustrates another embodiment of an HTR system of the invention useful in vacuum freezing with heat transfer from a first Heat Carrying Medium;

Fig. 9B illustrates the HTR system of Fig. 9A with heat transfer to a second Heat Carrying Medium;

Fig. 10A illustrates another embodiment of the HTR system of the invention useful in vacuum crystallization of an aqueous solution and non-aqueous mixtures with heat transfer from a first Heat Carrying Medium;

Fig. 10B illustrates the HTR system of Fig. 10A with heat transfer to a second Heat Carrying Medium;

Fig. 11A illustrates one embodiment of a multiple effect evaporating system incorporating HTR units of the invention and operated in a first cycle;

Fig. 11B illustrates the multi-effect evaporating system of Fig. 11A operated a second cycle;

Fig. 12A illustrates a multiple effect evaporator system similar to that of Fig. 11A and employing corrugated metal walls to form falling film evaporators and operated in a first cycle;

Fig. 12B illustrates the multiple effect evaporator of Fig. 12A operated in a second cycle;

Fig. 13 illustrates an automatic valving system of the invention;

Fig. 13A illustrates a single valve of the invention.

Detailed Description of the Preferred Embodiments

A heat temperature raising system (HTR system) of the present invention utilizes a heat temperature raising medium (HTR medium) that undergoes cyclic solidification and melting operations and one or more heat carrying mediums (HCM mediums) that undergo vaporization and condensation operations. An HTR system is used to take in heat at a low temperature heat source and discharge heat to a higher temperature heat sink.

Figure 1 illustrates the processing steps of an HTR system. In this and other figures, like numerals denote the same structure. In the system, a mass of HTR medium contained within a multitude of heat conductive and pressure sustaining conduits is subjected to a cyclic operations undergoing: (a) a first step of melting most of the HTR medium under pressure P_{HTR1} and temperature T_{HTR1}, [state 1 – state2]; (b) a second step of varying the medium pressure from P_{HTR1} to P_{HTR2} [state 2 – state 3]; (c) a third step of solidifying most of the HTR medium under pressure P_{HTR2} and temperature T_{HTR2} [state 3 – state 4]; and (d) a fourth step of varying the medium pressure from P_{HTR2} to P_{HTR1} [state 4 – state 1].

A first heat carrying medium [HCM-1 medium] receives heat from a low temperature heat source and thereby generates a first HCM medium vapor, HCM-1 medium vapor, which is condensed by releasing heat Q_L to the HTR medium in step 1. A second heat carrying medium [HCM-2 medium] receives heat from the HTR medium in step 3 to form a HCM-2 medium vapor, which is condensed by rejecting heat Q_H to the heat sink at an elevated temperature.

Figure 2 illustrates the construction of a Heat Temperature Raising unit (HTR unit). It comprises a multitude of heat conductive and pressure sustaining conduits 2, a mass of heat

temperature raising medium (HTR medium) 3, a header 4, and a cylinder and piston 5 for pressurizing and depressurizing the HTR medium. The use of a cylinder and piston is of course merely one example of a method for pressurizing the HTR medium. Other well-known methods will readily occur to those skilled in the art.

Figure 2A illustrates another heat temperature raising unit similar to that of Figure 2, except that there is a fin unit 6 installed in each conduit to enhance heat transfer. Figure 2B illustrates the structure of a longitudinal fin unit 6 and Figure 2C illustrates a cutaway view of a conduit 2 containing a fin unit 6.

Figure 3A illustrates a cross section of a unit of multiple connected conduits 7 unit formed by bonding two sheets 8 of corrugated material. The neighboring conduits are connected by wings 9. Figure 3B illustrated a cross section of a multiple conduit 7 unit similar to that of Figure 3A with a fin unit 10 installed in each conduit 7 to enhance heat transfer.

Figure 4A illustrates a cross section of a multiple conduit unit or a multiple tube assembly in which each conduit 7 is isolated from neighboring conduit. Figure 4B illustrates cross-sections of a multiple conduit unit similar to that of Figure 4A with a fin unit 10 installed in each conduit to enhance heat transfer.

Figure 5A illustrates a cross-section of multivoid metal blocks that has multiple conduits 12. Figure 5B illustrates a cross section of a unit similar to that of Figure 5A with a fin unit 13 in each of the conduits.

It is noted that the mass of the wall (M_W) of a HTR unit, e.g., walls of the conduits and header (see Figure 2) and block (see Figures 5A, 5B) is a major factor that affects the efficiency of the HTR operation. It is important to keep the ratio of the mass of the wall of the HTR unit (M_W) to the mass of HTR medium to a low value. Referring again to Figure 1, as the HTR unit is heated in step 2, the wall (not shown) is heated from T_1 to T_2 and thereby absorbs sensible heat. Therefore a part of the HTR medium is solidified to meet the energy balance relation. Thus, the amount of the remaining HTR medium to be solidified becomes less and the heat released in step 3 becomes less. Again in Figure 1, as the HTR unit is cooled in step 4, the wall is cooled from T_2 to T_1 and thereby releases sensible heat. Thus, a part of the HTR medium is melted to meet the energy balance relation. Therefore, the amount of the remaining HTR medium to be melted becomes less and the heat absorbed in step 1 becomes less. The problem described is referred to as "Thermal Inertia Problem". It is important to note that the higher the ratio of the mass of the wall of a HTR unit to the mass of the HTR medium, the more serious the "Thermal Inertia Problem" becomes and the lower the productivity of the HTR unit becomes and the lower the efficiency of the HTR unit becomes.

Suitable materials of construction of the HTR unit include aluminum, steel, copper, brass, and other metal and non-metal materials having sufficient heat transfer characteristics to permit acceptable heat transfer from the first Heat Carrying Medium and from the HTR unit to the second Heat Carrying Medium including heat transfer through the walls.

The mass ratio of the wall to the HTR medium is the lowest for a HTR unit with multiple tube assembly illustrated by Figures 4A and 4B. The mass ratio of the wall to the HTR medium is higher in a HTR unit with connected walls illustrated by Figures 3A and 3B. The mass ratio of the wall to HTR medium is the highest in a HTR unit made of a multivoid block illustrated by Figures 5A and 5B.

Thus, the use of a multivoid block is generally less preferred, because the mass ratio of wall to HTR medium is so high that the efficiency of HTR operation is low, its efficiency becomes so low that it is not very useful when the $T_2 - T_1$, referred to as temperature lift, is high.

Figures 6A and 6B show a HTR system that comprises a Heat Temperature Raising Zone 15, HTR Zone (Zone – 1), a flash cooling Zone 16 (Zone – 2), and a direct contact condensation Zone 17 (Zone – 3). Figure 6A shows that a feed liquid 21 is flash vaporized to be cooled and generate a heat carrying medium vapor V_1 (HCM-1 vapor). The HCM-1 medium vapor is then passed through an automatic valve 18 (made of, for example, a grating and flaps made of thin film), and it is brought in contact with the outer surface 22 of the HTR conduits for exchanging heat with the HTR medium in the HTR unit to thereby melt the HTR medium at T_{HTR1} and P_{HTR1}. Figure 6B shows that a mass of heat carrying medium is brought in contact with the HTR unit under pressure P_{HTR2} and at temperature T_{HTR2} to thereby generate a heat carrying medium vapor V_2 (HCM-2 vapor) and solidify the HTR medium. The HCM-2 medium vapor is then passed through an automatic valve 19, (made of, again for example, a grating and flaps made of thin film), and is brought in direct contact with a fluid 24 introduced in Zone-3 to contact the HCM-2 vapor and heat the said fluid. This system is useful in producing chilled water for air conditioning and also for other industrial cooling operations.

Figure 7A and 7B illustrate another HTR system that comprises a HTR Zone 15 (Zone 1), HCM-1 vapor generation Zone 16 (Zone-2A) and heat source Zone 26 (Zone 2B), a HCM-2 vapor condensation Zone 17 (Zone-3A) and a heat sink Zone 17 (Zone-3B). Figure 7A illustrates that a HCM medium is brought in heat exchange relation with a heat source in Zone-2B to generate HCM-1 vapor V_1 in Zone 2A. The HCM-1 vapor is condensed and the HTR medium is melted at T_{HTR1} and P_{HTR1} in Zone 1. Figure 7B shows that a mass of HCM-2 is applied on the outer surface 23 of the conduit of the HTR unit and is vaporized to form HCM-2 vapor V_2 and solidify the HTR medium at T_{HTR2} and P_{HTR2}. The HCM-2 vapor is then pass

through a second valve 19 and condensed in Zone-3A by releasing heat to a heat sink 27 in Zone-3B.

Figures 8A and 8B illustrate a HTR system used in a vacuum freezing operation. This system is useful in seawater desalination, industrial solution concentration, waste water concentration and crystallization of aqueous solution and non-aqueous mixtures. The system comprises a HTR Zone 29 (Zone-1), a vacuum-freezing Zone 30 (Zone-2), a crystal melting Zone 34 (Zone-3) and a crystal washing Zone 23 (Zone-4).

The processing steps conducted in the system are explained by referring to sea water desalination as an example. Referring to Fig 8A, a sea water feed is subjected to a deaeration and a heat exchange operation and is flash vaporized in Zone-2 to form a first low pressure water vapor that is designated as HCM-1 vapor V_1 and a mass of ice crystals 35. The pressures of the HCM-1 vapor is around 3.5 torr, which is lower than the triple point pressure of water (4.58 torr). The mass of ice crystals and the concentrated mother liquid form a slurry stream that is subjected to a crystal washing Zone 23 (Zone 4) and the purified ice is introduced to Zone-3. The low-pressure water vapor V_1 (HCM-1 vapor) is brought in contact with the HTR unit that is at pressure P_{HTR1} and temperature T_{HTR1}. The water vapor is desublimed to form a mass of desublimate (ice) 36 on the outer surfaces of the HTR unit and the HTR medium is melted. Referring to Figure 8B, the HTR unit is then subjected to pressure P_{HTR2} and temperature T_{HTR2} to generated a second water vapor V_2 (HCM-2 vapor) at a pressure around 5 torr, which is higher than the triple point pressure of water. The second water vapor V_2 is brought in contact with the ice in Zone 3 to thereby simultaneously melt the ice and condense the second water vapor V_2 as output stream 39. Both the condensate of the second vapor V_2 and the melt 39 of the ice become purified product water.

The system illustrated in Figures 9A and 9B is similar to that of Figures 8A and 8B and operations conducted in this system are also similar. In this system the HCM-2 vapor is brought into an indirect contact heat exchange with the purified crystals in Zone 3. Melt liquid exits in stream 47.

The system illustrated by Figures 10A and 10B is useful in vacuum crystallization of aqueous solution and non-aqueous mixtures. In this system the HCM-2 vapor formed is condensed by a cooling medium in Zone-3, and the crystal formed is not melted by the HCM-2 vapor. This system is particularly useful in ice block making whereby the small ice made in Zone 2 can be compressed to form ice block. This system is also very useful in conducting a distillative freezing process as described in U.S. Patent Nos.: 4218893, 4433558, 4451273 and 4578093, which are hereby incorporated by reference in their entirety.

Figures 11A and 11B illustrates a multi-effect evaporating system that comprises a first multiple effect evaporator, Z-1A, a second multiple effect evaporator, Z-1B, in the major processing Zone Z-1, a first HTR unit 61 in Z-2A and a second HTR unit 62 in Z-2B at the first end of the system, a third HTR unit 63 in Z-3A and a fourth HTR unit 64 in Z-3B at the second end of the system. The HTR units are operated cyclically and the multi-effect evaporators are operated nearly continuously.

The first multiple effect evaporator Z-1A comprises, as an example, nine evaporators 69-77 (ZE-1 through ZE-9) connected in series, with operating pressures decreasing successively in the direction from the left end ZE-1 toward the right end ZE-9. The second multiple effect evaporator Z-1B, comprises nine evaporators 78-86 (ZE′-1 through ZE′-9) connected in series, with operating pressures decreasing successively in the direction from the right end ZE'-1 toward the left end ZE'-9. It is readily understood that more or less than 9 effects may be used, the actual number being selected based on perameters such as operating conditions and economics.

Each of the four HTR units is operated cyclically and alternately serves as an evaporator and as a condenser. The four HTR units are operated in a coordinated manner. While one of the two HTR units at each end serves as an evaporator, the other unit serves as a condenser. As illustrated in Figure 11A, the HTR units in Z-2A and Z-3B serves as two vapor generators and the HTR units in Z-2B and Z-3A serve as two condensers.

The vapor streams generated are used as steam supplies to the two ZE-1 Zones and ZE'-1 Zones and thereby initiate the multiple effect evaporator operations. The vapor steams leaving the last effect ZE-9 and ZE'-9 are condensed in the two HTR-units serving as condensers. Figure 11B illustrates the same system in the other half of the cycle, in which the HTR units in Z-2B and Z-3A become the vapor generators and the HTR units in Z-2A and Z-3B become the condensers.

Figures 12A and 12B illustrate a multiple effect evaporator system similar to those illustrated by Figures 11A and 11B. In this system, corrugated metal walls 96, 97 are used to form falling film evaporators 89-95 and 98-104.

Figure 13 illustrates an Automatic valving system that provides vapor passages from one chamber to another without any mechanical actuating device or any electrical switch. The automatic valving system is made of a mesh 105 for structural support as well as a grating 107 for the two chambers with flaps 106 (made of thin film) attached on to the grating 107. The gratings with attached thin films function as dividers between two chambers. The thin film flaps 106 are pressure sensitive where when one chamber's pressure is higher than the other, the flap

will automatically opens allowing the vapor to flow from the first chamber with higher pressure to the second chamber with the low pressure. It automatically closes when the pressure of the second chamber becomes higher than that in the first chamber.

Figure 13A illustrates a single valve made of thin film flap attached onto a holder on the top of the vent.

In nature, heat flows from a high temperature heat source to a low temperature heat sink. The present invention discloses a process and apparatus with proper input of energy to accomplish just the opposite of what nature does. Theoretically the work input (applied pressure times the volume change of the HTR medium) to the HTR for a given amount of heat raised (the latent heat of HTR medium) per unit temperature rise is inversely proportional to the absolute temperature. This relationship may be derived from the Clausius-Clapeyron equation (Journal of Chemical Physics, Volume 25, No. 3), and can take the form: $\{P\Delta V/\Delta H\Delta T\}=1/T$, representing the law of heat temperature raiser. This invention is based on the principle that as the applied pressure changes the melting point changes.

There are generally two types of compounds suitable for an HTR medium: a Type A substance is the most common, for which, as the pressure applied on the medium increases, its melting point increases. Thus, the said medium will absorb heat at low temperature and low pressure; and as the applied pressure increases, the melting point of the medium increases, allowing it to release heat and solidify at a higher temperature. For a Type B substance, such as water, as the applied pressure increases, the melting temperature decreases. As the pressure applied upon ice increases, the melting point decreases whereby allowing ice to absorb heat at temperature below 0°C to melt and again solidify at 0°C as the pressure is released. Nonetheless, both types of substances can be used to absorb heat at a lower temperature and to release heat at a higher temperature by subjecting the medium to a pressure variation. Therefore, any medium with proper variation in melting point can be used as a Heat Temperature Raising Medium. Suitable Heat Temperature Raising Medium include compounds having melting points ranging from between –30°C and 100°C as described, for example, in the Handbook of Chemistry and Physics, which is incorporated herein by reference. Any resulting mixture should have a eutectic point range of between –30°C and 100°C. A mixture can also be used as a HTR medium. The figures will now again be discussed in further detail.

In the system of Figure 1, a mass of HTR medium contained within a multitude of heat conductive and pressure sustaining conduits is subjected to a cyclic operations undergoing: (a) a first step of melting most of the HTR medium under pressure P_{HTR1} and temperature T_{HTR1}, [state 1 – state2]. (b) a second step of varying the medium pressure from P_{HTR1} to P_{HTR2} [state 2 – state

3]. (c) a third step of solidifying most of the HTR medium under pressure P_{HTR2} and temperature T_{HTR2} [state 3 – state 4], and (d) a fourth step of varying the medium pressure from P_{HTR2} to P_{HTR1} [state 4 – state 1]. A first heat carrying medium [HCM-1 medium] receives heat from a low temperature heat source and thereby generate a first HCM medium vapor, HCM-1 medium vapor, which is condensed by releasing heat Q_L to the HTR medium in step 1. A second heat carrying medium [HCM-2 medium] receives heat from the HTR medium in step 3 to form a HCM-2 medium vapor, which is condensed by rejecting heat Q_H to the heat sink at an elevated temperature.

Still referring to Figure 1, the masses of HTR medium in the solid and liquid states in state 1 are respectively represented by $(m_S)_{HTR,1}$ and $(m_L)_{HTR,1}$; the masses of HTR medium in the solid and liquid states in state 2 are respectively represented by $(m_S)_{HTR,2}$ and $(m_L)_{HTR,2}$; the mass of HTR medium in the solid and liquid states in state 3 are respectively represented by $(m_S)_{HTR,3}$ and $(m_L)_{HTR,3}$; the mass of HTR medium in the solid and liquid states in state 4 are represented by $(m_S)_{HTR,4}$ and $(m_L)_{HTR,4}$. Then, the heat taken in at the low temperature heat source Q_L is given by: $Q_L=\{(m_L)_{HTR,2}-(m_L)_{HTR,1}\} \times \lambda_m$ where λ_m is the latent heat of melting of the HTR medium. It also shows that the heat given to the high temperature heat sink minus Q_H is given by: $-Q_H=\{(m_S)_{HTR,4}-(m_S)_{HTR,3}\} \times \lambda_m$. As the HTR unit changes its temperatures from $T_{HTR,4}$ to $T_{HTR,1}$, the HTR unit releases sensible heat. Therefore, a portion of the HTR medium melts to satisfy the energy balance relation. Therefore, $(m_L)_{HTR,1}$ is greater than $(m_L)_{HTR,4}$. This makes the heat removable from the low temperature heat source smaller. Similarly, as the HTR unit changes its temperature from $T_{HTR,2}$ to $T_{HTR,3}$ the HTR unit absorbs sensible heat. Therefore, a portion of the HTR medium solidifies to satisfy the energy balance relation. Therefore, $(m_S)_{HTR,3}$ is greater than $(m_S)_{HTR,2}$. This makes the heat available to the high temperature heat sink smaller. The loss in the amount of heat transferable is referred to as "Thermal Inertia Problem." It can be shown that as the mass of the HTR conduits increases, the more serious the Thermal Inertia Problem becomes, and the greater the temperature lift, $\{T_{HTR,2}-T_{HTR,1}\}$ is the more serious the Thermal Inertial Problem becomes.

The figure also shows that one may use the same substance for both HCM-1 and HCM-2 mediums. In this case, one may use as the HCM-1 a condensate obtained in the low temperature condensation operation as the HCM-2 medium and subject it to a high temperature vaporization operation and one may also used the HCM-2 condensate formed in the high temperature condensation operation as the HCM-1 medium and subject it to a low temperature vaporization operation.

Figure 2 illustrates the construction of a heat temperature raising unit (HTR unit) 1. It comprises a multitude of heat conductive and pressure sustaining tubes 2, a mass of heat temperature raising medium 3, a header 4, and a cylinder and a piston 5 for pressurizing and depressurizing the HTR medium. This pressure device can be just a piston or any other type of pressurizing device.

By changing the pressure applied to the Heat Temperature Raiser unit, the Heat Temperature Raising Medium (HTR medium) 3 absorbs heat at a low temperature and releases heat at a higher temperature. The present invention will be illustrated by use of a type A substance as a Heat Temperature Raising Medium. The HTR at a low pressure melts and store the heat in the form of latent heat of the HTR medium. As the applied pressure is increased, the melting point of the HTR medium increases. Under the higher pressure, the latent heat of the medium HTR medium will be released at a higher temperature, and the HTR medium will solidify again. Therefore by changing the applied pressure, HTR will allow the HTR medium to perform a batch processing of the elevating heat temperature from a lower temperature to a higher temperature. The faster the rate of the heat transfer through the conduits of the Heat Temperature Raiser, the faster the HTR medium can absorb and release its latent heat. Therefore, the pressure changes have to take place faster. Therefore the amount of the heat temperature raising per unit length of the conduits of the HTR per unit time will be greater. A set of fins can be installed inside of the conduits to increase the rate of the heat transfer within the HTR medium. Figure 2A shows a HTR unit similar to that of Figure 2, except that there are a set of longitudinal fins 6 installed in the conduits. Figure 2B shows the construction of a longitudinal fin. Figure 2C shows a partial cut away view of a conduit with a longitudinal fin installed therein.

The conduit of the Heat Temperature Raiser is made of a heat conductive and pressure sustaining material. There are different ways of constructing conduits used in constructing a HTR unit:

Figure 3A illustrates a set of conduits 7 formed by bonding together corrugated plates 8. The neighboring conduits are connected by wings 9. Figure 3B illustrates a set of conduits with connecting wings similar to that shown in Figure 3A, except that longitudinal fins are installed within the conduits.

Figure 4A illustrates a set of conduits 7 that have substantially uniform wall thickness 8 and that the conduits are individually separated without having any connecting walls between two neighboring conduits. Figure 4B shows a similar unit with fins 10 in the conduits.

Figure 5A illustrates a multivoid metal block having conduits that do not have substantial uniform thicknesses. Figure 5B illustrates a similar structure with fins in the conduits.

During the high-pressure operation of the HTR, the melting point of HTR medium will increase as the pressure is increased, thereby allowing the HTR medium to release heat at the higher temperature. At the same time, the outer wall of the conduits of the HTR will also increase its temperature by absorbing heat released by HTR medium. After pressure is released from HTR, the pressure of HTR will decrease and the melting point of the HTR medium will decrease which will allow the HTR medium to absorb heat at the lower temperature while the outer walls of the conduit of the HTR will reduce the temperature by releasing heat. The effectiveness of HTR in upgrading heat temperature of the HCM medium from a low temperature heat source to a higher temperature heat sink is dependent on the amount of latent heat of HTR medium elevated by the batch process of HTR minus the amount of sensible heat used by the outer walls of the conduits. Therefore, the less sensible heat used by the outer wall of the conduits, the more effective the HTR in upgrading heat temperature will be. Thus, materials with less sensible heat retention used in constructing the HTR, the less sensible heat will be lost, and the effectiveness of the HTR will increase.

Therefore, in the above mentioned types of conduits, a set of conduits with relatively uniform wall thickness is preferred over the multivoid block conduits for constructing HTR because a set of conduits with relatively uniform wall thickness will minimize the loss of sensible heat per unit volume of conduit. The amount of the material used by the multivoid block conduits is too large causing too much sensible heat loss per unit volume of conduit; thus it is not preferred and may not be suitable for use in the HTR to elevate heat temperature in the HTR. On the other hand, a set of the conduits with relatively uniform wall thickness has a relatively small mass of material used in the walls of the conduits which can reduce the loss in effectiveness due to the sensible heat per unit volume of the conduit.

By alternating between high-pressure and low-pressure in the HTR, the temperature of HCM medium vapor will increase; whereby HCM medium vapor will condense onto the HTR allowing its latent heat to transfer through the walls of the conduits into the HTR medium and allow the latent heat to liquefy the HTR medium. As the pressure of HTR is increased, the melting point of the HTR medium will increase and the HTR medium will transfer its latent heat at a higher temperature out of the HTR and back to the HCM medium. The capacity of the heat elevation of the HTR depends on the speed of the HTR pressure alternation between high-pressure and low-pressure. The alternation between high-pressure and low-pressure of HTR is

dependent on the rate of the heat of HCM medium transferring into HTR medium or the rate of heat of HTR medium transferring back out to HCM medium.

The heat transfer resistance in condensing HCM-1 vapor is low and the heat transfer resistance through the conduit wall is low. The major heat transfer resistance is in the heat transfer through the HTR medium itself.

The condensing rate of HCM medium vapor is very fast, and the heat transfer rate through the wall of the conduits is very fast, but the heat transfer rate of the HTR medium inside the metallic tube is very slow. Therefore, the rate of the alternation of HTR between high-pressure and low-pressure depends on the heat transfer rate of the medium inside the HTR. Hence, in order to increase the rate of the heat transfer resistance of the HTR medium in the conduits, it is necessary to install a set of fins inside the conduits of the HTR. There are many types of fins such as longitudinal radial fins and longitudinal radial fins with holes on the fins. There are many methods and materials can be used to form these heat conductive fins. For example, a piece of thin metal may be folded in a zigzag shape and then formed into a circular shape as shown in figure 2B to become a longitudinal radial fin. One skilled in the art can readily select a fin design from many well-known designs. The fins will greatly increase the heat transfer rate of the medium inside the HTR because the radial fins transfer heat in the radial direction of the tube. The installation of the fins will greatly reduced the heat transfer resistance of the HTR and allow increase in the speed of the pressure alternation of the HTR, and thereby increase the heat raising capacity of the HTR.

The Heat Temperature Raiser (HTR) is preferably a stationary device only acting as an elevator to elevate the temperature of the latent heat of the HTR medium. It does not by itself have the ability to transfer heat from the low temperature heat source to the higher temperature heat sink. Therefore, one or two Heat Carrying Mediums (HCM mediums) are needed to assist in transferring heat from low temperature heat source to a higher temperature heat sink. Any compound that has proper vapor pressure at the desired operating temperature can be used as the Heat Carrying Medium.

HCM-1 medium in the Zone with heat source either enters in direct contact or through a heat exchanger absorbs heat from the heat source and vaporizes itself to become HCM-1 vapor. The HCM-1 medium vapor flows to the Zone where HTR is located and condenses onto the surface of the HTR. As HCM-1 medium vapor condenses on the surface of the HTR, HTR medium solid melts and the heat absorbed by the HTR medium is stored as the latent heat of the HTR medium. After the HTR medium is melted, a high pressure is applied onto the HTR medium to elevate the melting point of the HTR medium to a high temperature. At the same

time; the applied high pressure will cause the latent heat of melting to be elevated to a higher temperature as well. Then, the HTR medium releases heat to the HCM-2 medium and the HCM-2 medium vaporizes at a higher temperature. The HCM-2 medium vapor enters into the higher temperature heat sink Zone where HCM-2 vapor releases heat to the higher temperature heat sink through direct or indirect heat exchange. The whole process of this invention comprises subjecting the HTR medium inside of the HTR unit to batch processing of elevating the heat temperature; and subjecting the HCM mediums to vaporization, condensation, absorbing, and releasing of the heat. The HCM mediums perform the functions of transferring heat from a low temperature heat source to a high temperature heat sink. Therefore, a Heat Temperature Raising System comprises a Heat Temperature Raiser, a Heat Temperature Raising Medium, and one or two Heat Carrying Mediums.

Since the process for elevating heat temperature by the HTR is a batch process, the amount of latent heat of HTR medium elevated from each batch is limited. Thus, when the amount of the latent heat produced by one process is not enough to cover the sensible heat loss of the outer walls of the conduits, multiple sets of HTR systems can be used to elevate the process stepwise to the desired temperature.

Under different types of heat source, there are different operation methods. The methods are as follows:

When the heat source and the HCM medium cannot be allowed to make direct contact, a heat exchanger can be used for the heat transfer. For example, in an air conditioning operation, water is used as HCM-1 and room air serves as the heat source and an indirect heat exchange takes place.

When the heat source and the HCM medium may make direct contact, HCM medium absorbs heat directly from the low temperature heat source and HCM-2 medium condenses and releases the heat to the high temperature heat sink. For example, one may use a water insoluble substance as HCM medium to remove heat from an aqueous solution.

The material processed may provide a HCM medium and also serves as the heat source. For example, in flash vaporizing an aqueous solution, a part of the water becomes HCM-1 and the remaining part serves as heat source.

Exothermal chemical reaction produces heat for vaporizing Heat Carrying Medium to produce HCM medium vapor.

A unit of HTR is shown in Figure 2, whereby the Heat Temperature Raising Unit 1 has the multitude of heat conductive pressure sustaining conduit 2, and a heat temperature raising medium 3 filled inside of the conduit 2 and a header 4 and a pressurizing device 5.

In order to increase heat transfer rate one may install a longitudinal radial fin 6 inside of each of the heat conductive pressure sustain conduits 2 as shown in Figure 2A.

The system illustrated by Figures 3A, 4A, and 5A illustrates the cross section taken at section AA of Figure 2 and Figures 3B, 4B, and 5B illustrates the cross section taken at section AA of Figure 2A.

Figure 3A illustrates a cross section view of a multiple connected conduits containing HTR medium 7 and heat conductive conduit with pressure sustaining wall 8 and connecting walls between neighboring conduits 9. Figure 3B illustrates a cross section view of a multiple connected conduits containing HTR medium 7 and heat conductive conduit with pressure sustaining wall 8 and connecting walls between neighboring conduits 9 and a heat conductive fin 10 installed inside of the conduit. Figure 4A illustrates a cross section view of a multiple tube assembly containing HTR medium 7 and heat conductive and pressure sustaining wall 8 enclosing each conduit. It shows that there are no connecting walls between two neighboring conduits. Figure 4B illustrates a cross section view of a multiple tube assembly containing HTR medium 7 and heat conductive and pressure sustaining wall 8 enclosing each tube and it shows there are no connecting wall between two neighboring tube and a heat conductive fin 10 installed inside of the tube. Figure 5A illustrates a cross section view of multivoid heat conductive block containing multitude of conduits 11 which containing HTR medium 12. Figure 5B illustrates a cross section view of multi void heat conductive block containing multitude of conduits 11 which containing HTR medium 12 and a heat conductive fin 13 installed inside of the conduit.

The system illustrated by Figures 6A and 6B is a vapor pressure raising system. It comprises a vapor pressure raising Zone Z-1 15, a low pressure first vapor generation Zone, Z-2 16, and high pressure vapor condensing Zone Z-3 17, and a valve 18 connecting from Zone Z-2 to Zone Z-1 and a valve 19 connecting from Zone Z-1 to Zone Z-3. Figure 6A illustrates that the first step of generating first vapor, HCM-1 vapor, in Zone 2. Adjusting the pressure of the HTR medium at the first pressure, where the melting temperature of the HTR medium is lower than the condensing temperature of the first vapor, HCM-1 vapor, thereby condensing the first vapor, HCM-1 vapor, and melting the HTR medium inside of the HTR conduits. Upon actuating a pressure variation device, one can control the transformation temperature such that the first vapor, HCM vapor, generating in Zone 2 enters through a self actuating valve (made of a grating and flaps made of thin films attached on to the grating) 18 transfers heat from the first vapor, HCM vapor, to HTR medium thereby condenses the HCM-1 vapor into the solid or liquid form and melts the HTR medium.

Figure 6B illustrates that upon applying the pressure to the medium by actuating the HTR pressurizing device, and applying a HCM-2 liquid outside of the HTR conduits, heat transfers from the HTR medium to the HCM-2 liquid thereby solidifies the HTR medium and vaporizes the HCM-2 liquid thereby forming a high pressure vapor, HCM-2 vapor. The HCM-2 vapor flows from Zone 1 to Zone 3 through another self actuating valve 19 to thereby condense inside of Zone 3.

The system illustrated by Figures 7A and 7B are similar of those of Figures 6A and 6B with two added Zones; a low temperature heat source Zone and a high temperature heat sink Zone. Figure 7A and 7B illustrate a system for providing air conditioning or producing chill water. It comprises vapor pressure raising Zone Z-1 and first vapor generating Zone Z-2A and second vapor condensing Zone Z-3A and low temperature heat source Zone Z-2B containing low temperature heat exchanger coil 26 and high temperature heat sink Zone Z-3B containing high temperature heat exchanger coil 27. Air or water is introduced into Zone Z-2B to exchange heat with the process liquid HCM medium thereby forming a first HCM1 vapor. The first HCM1 vapor enters into Zone Z-1 heat exchange with HTR medium condenses therein and melts the HTR medium. Referring to Figure 7B the pressure is adjusted to raise the solidification temperature of HTR medium and applying process liquid on the outside of the heat transfer conduits. Thereby, heat is transferred from the HTR medium to the process liquid and solidifying the HTR medium and generating a second HCM-2 vapor. Second HCM-2 vapor enters into Zone Z-3A and the air is circulated in Zone Z-3B. The second HCM-2 vapor is heat exchanged with air or water in Zone Z-3B to thereby condenses and heat is removed by the outside air or cool water.

The system illustrated by Figures 8A and 8B are similar to that of Figures 6A and 6B. In this system, simultaneous vaporization and freezing operations take place to produce HCM-1 vapor and a mass of solid of the process substance. Figures 8A and 8B illustrate a system for providing pure water. It comprises vapor pressure raising Zone Z-1 and first vapor generating Zone Z-2 and second vapor condensing Zone Z-3 and a crystal washing Zone Z-4. The process substance 32 is feed into the Zone Z-2 to generate first HCM1 vapor and solid simultaneously. The solid generated in Zone Z-2 along with mother liquid is sent to the Zone Z-4 for crystal washing. The first HCM1 vapor generated in Zone Z-2 enters into Zone Z-1 heat exchange with HTR medium condensed therein and melts the HTR medium. Figure 8B illustrates the pressure is adjusted to raise the solidification temperature of HTR medium and applying process liquid on the outside of the heat transfer conduits. Thereby, heat is transferred from the HTR medium to the process liquid and solidifies the HTR medium, generating second HCM-2 vapor. The

washed crystals 33 from Zone Z-4 are then sent to Zone Z-3 to allow the second HCM-2 vapor to condense and thereby melt and generate pure water 39.

The system illustrated in Figures 9A and 9B is similar to that of Figures 8A and 8B and operations conducted in this system are also similar. In this system the HCM-2 vapor is brought into an indirect contact heat exchange with the purified crystals in Zone 3.

The system illustrated by Figures 10A and 10B is useful in vacuum crystallization of aqueous solution and non-aqueous mixtures. In this system the HCM-2 vapor formed is condensed by a cooling medium in Zone 3, and the crystal formed is not melted by the HCM-2 vapor. This system is particularly useful in making ice blocks whereby the small pieces of ice made in Zone 2 can be compressed to form an ice block. This system is also very useful in conducting the distillative freezing process invented by Chen-Yen Cheng and Sing-Wang Cheng and described in U.S. Patent Nos.: 4218893, 4433558, 4451273 and 4578093.

Figures 11A and 11B illustrate a multi-effect evaporating system that comprises a first multiple effect evaporator, Z-1A, a second multiple effect evaporator, Z-1B, in the major processing Zone Z-1, a first HTR unit 61 in Z-2A and a second HTR unit 62 in Z-2B at the first end of the system, a third HTR unit 63 in Z-3A and a fourth HTR unit 64 in Z-3B at the second end of the system. The HTR units are operated cyclically and the multi-effect evaporators are operated nearly continuously.

The first multiple effect evaporator Z-1A comprises, as an example, nine evaporators ZE-1 through ZE-9, 69 through 77 connected in series, with operating pressures decreasing successively in the direction from the left end ZE-1 toward the right end ZE-9. The second multiple effect evaporator Z-1B, comprises nine evaporators ZE'-1 through ZE'-9, 78 through 86 connected in series, with operating pressures decreasing successively in the direction from the right end ZE'-1 toward the left end ZE'-9.

Each of the four HTR units is operated cyclically and alternately serves as an evaporator and as a condenser. The four HTR units are operated in a coordinated manner. While one of the two HTR units at each end serves as an evaporator, the other unit serves as a condenser. As illustrated in Figure 11A, the HTR units 61 in Z-2A and Z-3B 64 serves as two vapor generators and the HTR units in Z-2B 62 and Z-3A 63 serve as two condensers.

The vapor streams generated are used as steam supplies to the two ZE-1 Zones and ZE'-1 Zones and thereby initiates the multiple effect evaporator operations. The vapors leaving the last effect ZE-9 and ZE'-9 are condensed in the two HTR-units serving as condensers. Figure 11B illustrates the same system in the other half of the cycle, in which the HTR units in Z-2B

and Z-3A become the vapor generators and the HTR units in Z-2A and Z-3B become the condensers.

Figures 12A and 12B illustrate a multiple effect evaporator system similar to those illustrated by Figures 11A and 11B. In this system, corrugated metal walls are used to form falling film evaporators. The operations of this system are similar to those described in connection with figures 11A and 11B.

Figure 13 illustrates a self actuating valving system that provides vapor passages from one chamber to another without any mechanical device or any electrical switch. The valving system is made of a mesh 105 for structural support as well as a divider for the two chambers with flaps 106 (made of thin film) attached onto the divider. These dividers with attached thin films 106 will be the dividers between two chambers. The thin film flaps 106 are pressure sensitive wherein when one chamber's pressure is higher than the other, the flap will automatically opens allowing the vapor to flow from the first chamber with higher pressure to the second chamber with low pressure. It automatically closes when the pressure of the second chamber becomes higher than the pressure in the first chamber.

Figure 13A illustrates a single vent made of thin film 106 attached onto a holder 107 on the top of the vent.

The concept of the present invention has a wide range of usage, such as air condition, water purification, distillative freezing, ice making, waste water treatment, desalinization, distillation operation under ambient temperature or high temperature, or organic chemical purification and separation, and other areas which may require the use of raising heat temperature from low temperature heat source to a high temperature heat sink.